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Patent Application of

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for

Fabrication and Controlled Release of Structures Using Etch-Stop Trenches

FIELD OF THE INVENTION

This invention relates generally to microelectromechanical systems (MEMS). More particularly, it relates to forming structures on MEMS devices.

CROSS REFERENCE TO RELATED APPLICATION

This application is based on Provisional application 60/192,144, filed March 24, 2000, which is herein incorporated by reference.

BACKGROUND

Large topology MEMS structures have applications for actuators, where the actuation force can be greatly increased by increasing the actuator area; optical devices, where high aspect ratios are needed to interact with optical beams, bio-MEMS, where high aspect ratio channels and sensors may be required; and a number of other applications where it is desirable to use a semiconductor compatible process to generate large topology structures.

A number of methods currently exist for forming large topology structures in MEMS processes, however, all have distinct disadvantages in process compatibility with following steps and/or in process complexity.

One common approach uses deep UV or X-ray lithography to define high aspect ratio features in photoresist or polymer and then electrodeposit metallic material inside the photoresist features. However, once the photoresist or polymer is removed, tall features are left on the wafer, preventing the use of standard resist and deposition processes for further processing. Also, the use of metallic materials to form the features prevents high temperature steps in further processing. Finally, this method requires the use of expensive X-ray lithography sources, which are not commonly used in semiconductor processing, for forming features.

Another method uses standard photoresist processing followed by a deep anisotropic etch (for example into the device layer of an SOI wafer) to form deep features. As in the previous method, this process leaves tall features on the wafer, preventing further standard processing. If the trenches formed by this process are narrow enough, they may be planarized by depositing a conformal film of sacrificial material, however, in this case the features are limited to having very small trenches (typically 2μm or less in depth) significantly limiting the types of structures that may be defined.

SUMMARY

The disadvantages associated with the prior art are overcome by the present invention of methods for fabrication and controlled release of structures. The structures may be fabricated on a substrate by forming one or more trenches in a device layer. The trenches are subsequently filled with an etch-stop material. Material in the device layer is then isotropically etched in selected portions bounded by one or more of the filled trenches. The etching undercuts one or more portions of the etch-stop material that has been deposited over the surface of the device layer. The etch-stop material

may be used to form structures that are released by the etch process. Alternatively, the structures may be formed by a different type of material deposited over the device layer and/or etch-stop material. This approach provides a controlled release method where the exact timing of the isotropic release etch becomes non-critical. Further, using this method, structures with significant topology may be fabricated while keeping the wafer topology to a minimum during processing until the very end of the process. The present invention also includes structures fabricated in accordance with the method outlined above. This embodiment of the invention is particularly suitable for comb drive structures, such as those used in MEMS devices.

DESCRIPTION OF THE FIGURES

Figs. **1A-1E** depict cross sectional schematic diagrams illustrating formation of a MEMS device according to a first embodiment of the invention;

Figs. **2A-2F** depict cross sectional schematic diagrams illustrating formation of a MEMS device according to a second embodiment of the invention;

Figs. **3A** depicts an isometric view of a comb structure manufactured according to a third embodiment of the invention;

Figs **3B-3C** depict cross sectional side views of alternative embodiments of comb structures manufactured according to the present invention.

DETAILED DESCRIPTION

Although the following detailed description contains many specifics for the purposes of illustration, anyone of ordinary skill in the art will appreciate that many variations and alterations to the following details are within the scope of the invention. Accordingly, the following preferred

embodiment of the invention is set forth without any loss of generality to, and without imposing limitations upon, the claimed invention.

A first exemplary embodiment of process is useful for forming high aspect ratio structures on a substrate and releasing structures formed on a substrate is shown in Figs. **1A-1E**. The structures are typically formed in a device layer **102**. The device layer **102** may be the top layer of a silicon-on-insulator (SOI) substrate, the substrate itself, or a glass, quartz, or oxide layer deposited on top of a substrate. In this embodiment, the structures are formed on and released from an SOI substrate **101** depicted in Fig. **1A**. The SOI substrate **101** generally comprises the device layer **102** disposed on an intermediate **104**, which is disposed on a substrate layer **106**. The device layer **102**, intermediate layer **104**, and substrate layer **106** may be made from semiconductor materials, e.g., Si, GaAs, etc., metals e.g., Al, Cu, Ti, W, Au, etc., or insulators, e.g. oxides. The device layer **102** and the substrate layer **106** may be made of the same material as each other. Generally, the intermediate layer **104** is made of a material that is different from that of the device and substrate layers. The material of the intermediate layer is preferably made from a material that is etchable by a process that does not attack the device layer **102** or the substrate layer **106**.

As shown in Fig. **1B**, narrow trenches **108** are formed in the device layer **102** by patterning a standard resist and etching the device layer. The trenches **108** are then completely filled with an etch-stop material **110** as shown in Fig. **1C**. Suitable etch-stop materials include silicon nitride, polycrystalline silicon, silicon dioxide, tungsten, etc. The etch-stop material is typically deposited using chemical vapor deposition. Alternatively, sputtering or electroplating may

be used to deposit the etch-stop material **110**. The etch-stop material completely fills the trenches, forming filled trenches **110**. The etch-stop material **110** may be also deposited over a surface of the device layer **102**, which would typically happen in the same deposition step. Alternatively, a separate deposition may be required for this. At this point the surface of the device layer **102** is largely planar and any further processing may be performed using standard semiconductor processes. Also, since the etch-stop material may be deposited at high temperature, further high-temperature processing is not prevented.

Once all processing has been performed, a photoresist and/or etch-stop material **110** is patterned to expose selected portions **114** of the device layer **102**, as shown in Fig. **1D**. The patterning of the etch-stop material **110** defines one or more structures **120** bounded by one or more of the filled trenches **110**. The etch-stop material **110** may be etched using standard semiconductor techniques, e.g., wet etch, plasma etch, etc. Although, the structures **120** are depicted as being entirely formed by the etch-stop material **110**, the structures **120** may include other materials in addition to the etch-stop material **110**. Next, an isotropic etch of device layer **102** is performed, as shown in Fig. **1E**. During this step the material in the exposed portions **114** of the device layer **102** is etched, but the etch-stop material is not etched. In the embodiment depicted in Figs. **1A-1E**, the insulator **104** is also resistant to the isotropic etch process. Thus, the isotropic etch removes material from portions of the device layer **102** that are bounded by one or more filled trenches **112** and the intermediate layer **104**. The isotropic etch may be a wet etch process or dry etch process or some combination of both. The isotropic etch undercuts and releases structures **120** defined on top of the device layer by the patterning depicted in Fig. **1D**. The structures **120** may be secured to the etch-stop

material **110** or the device layer **120** at some point or points outside the plane of the drawing in Fig. **1E**. The etch is contained by the etch-stop material **110** in the filled trenches **112**. Thus, the spacing of the filled trenches **112** controls the width of the undercut. At this point, the structures **120** are fully defined and the devices are ready for use or a final release, depending on the process.

In the process described above with respect to Figs. **1A**-**1E**, the structures **120** were formed from the etch-stop material. In an alternative embodiment, structures may be formed using a material different from the etch-stop material. An application of this process may be used, for example, to form comb structures for electrostatic actuators, capacitive sensors, or other applications. The process for fabricating such a structure is shown in Figs. **2A**-**2F**. In Fig. **2A**, the process starts with a substrate **201** having a device layer **202** disposed on an intermediate layer **204**, which is disposed on a substrate layer **206**. The device layer **202** may alternatively be the substrate itself, or a layer of device material such as glass, quartz, or oxide deposited on top of a substrate. The device layer **202** is patterned to define one or more features, e.g. using a standard resist. The features are then etched to form one or more narrow trenches **208** in the device layer **202**, as shown in Fig. **2A**. The trenches **208** may penetrate into the oxide layer **204** and/or the substrate layer **206**. The trenches **208** are then completely filled with an etch-stop material **210** as described with respect to Fig. **1C**, to form one or more filled trenches **212**. The etch-stop material may also be deposited on top of the device layer **202**.

Selected portions of the etch-stop material **210** are removed to expose selected portions of the device layer **202**, as shown in Fig. **2D**. Structural features **222**, such as comb fingers, are then formed on the exposed portions of the device layer **202**.

Alternatively, the structural features **222** may be formed directly on top of the etch-stop material **210** as opposed to the device layer **202**. The structural features **222** are typically made of a material that is different from the etch-stop material **210**. Alternatively, the features **222** may be formed from the same material, but in a later deposition step. The structural features **222** may be formed from a patterned structural layer containing multiple sub-layers of material. The structural features **222** are secured to the structural layer **202** at some point or points outside the plane of the drawing in Figs. **2E-2F**. Once all processing of the structural features **222** has been performed, the photoresist and/or the etch-stop layer is patterned to expose the device layer in appropriate places as shown in Fig. **2E**. Next, an isotropic etch of the device layer is performed as shown in Fig. **2F**. During this step the exposed device layer material will be etched, undercutting and releasing the structures on top of the device layer as described above with respect to Fig. **1E**. The etch is contained by the etch-stop material **210** in the filled trenches **212**, controlling the width of the undercut. At this point, the structures are fully defined and the devices are ready for use or a final release, depending on the process.

The above methods may be used to fabricate different types of structures. Such structures may have greater topology, i.e., greater heights above the device layer, than in the prior art. For example, Fig. **3A** depicts an embodiment of a comb structure manufactured according to the present invention. The comb structure **300** generally comprises a static comb member **301** having one or more comb fingers **302** and a movable comb member **303** having one or more comb fingers **304**. The fingers **302**, **304** of the fixed and movable comb members **301, 303** interdigitate. Such a structure is useful in a comb-drive actuator device. In one example of such an actuator, an electric field between

the fixed and movable comb fingers **302**, **304** causes the movable fingers **302** to deflect in response to an electrostatic force.

Although the fixed and movable comb fingers **302**, **304** are depicted as being at substantially the same level, other arrangements are possible. For example, in the side cross sectional view depicted in Fig. **3B** movable comb fingers **302'** are disposed above static comb fingers **304'**. In such a case a voltage between the static comb fingers **304'** and the movable comb fingers **302'** would produce an electric force that would cause the movable comb fingers **302'** to deflect downward. Alternatively, as depicted in the side cross sectional view in Fig. **3C** movable comb fingers **302"** are disposed below static comb fingers **304"**. In such a case a voltage between the static comb fingers **304"** and the movable comb fingers **302"** would produce an electric force that would cause the movable comb fingers **302"** to deflect upward.

It will be clear to one skilled in the art that the above embodiments may be altered in many ways without departing from the scope of the invention. Accordingly, the scope of the invention should be determined by the following claims and their legal equivalents.